Radiologisk konsekvensanalyse ved utslipp av radionuklider fra IFE

Task 1: Preliminary model definition and parametrization

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1 Introduction

The Institute for Energy Technology (IFE) is an independent research foundation, established by the government of Norway in 1948, with approx. 1 billion NOK annual turnover and around 600 employee [1]. When founded, IFE's main goal was nuclear research, but currently IFE is one of the leaders in petroleum, environmental and nuclear technology as well as energy research and safety. Throughout the years IFE has been devoted to many projects aiming at the development of smart and environment-friendly industrial processes and transport solutions as well as pharmaceutical and renewable energy sector.

IFE is organized in three divisions, each of them further divided into sectors and departments.

- Research and Development (R&D)
- Radiopharmacy
- Nuclear Technology

The IFE is currently responsible for managing several nuclear facilities located in Norway (Kjeller and Halden sites). The facilities located in Kjeller are situated 3 km north-east of the town of Lillestrøm and around 20 km north-east of Oslo (Figure 1-1).

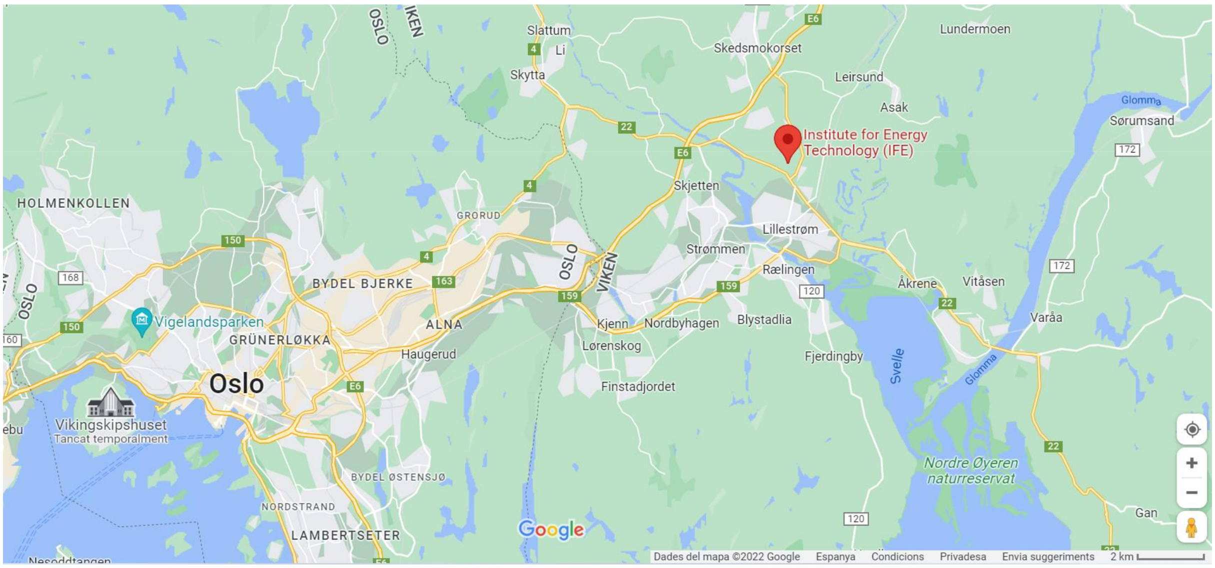

***Figure 1-1:** Localization of IFE-Kjeller's site [2].*

IFE holds a permit for liquid and airborne discharges from the facilities, issued pursuant to the Act of 13 March 1981 No.6 Protection Concerning Against Pollution and Waste [3]. This permit allows for the receipt, treatment and intermediate storage of radioactive waste from the isotope production, research reactors and research activities, as well as radioactive waste from external users. Additionally, it provides authorisation for radioactive discharges to air and water from the reactor operations, production of fuel, tracers and radiopharmaceuticals, investigations of irradiated fuel and treatment of radioactive waste at the company´s waste facility. IFE is obliged to reduce its emissions as far as possible without unreasonable costs even if all the discharges are kept within the emission limits.

The split of IFE into three independent divisions requires a new regulatory permit for liquid and airborne discharges to the environment during normal operations for each of them. IFE has been required by the DSA (Norwegian Radiation and Nuclear Safety Authority) to perform a new environmental risk assessment including all relevant substances IFE has permission or requests permission to release. DSA has sent a series of letter to IFE where it is stated some requirements to be considered in the forthcoming environmental assessment.

1.1 Objective

The objective of this project is to perform an environmental impact assessment of the discharge of radioactive substances from IFE Kjeller plants both to human and non-human biota. The environmental impact assessment will be conducted per each of the IFE's divisions following the same base conceptual model in all cases.

The project is divided into four tasks:

- Task 1: Preliminary model definition and parametrization
- Task 2: Impact assessment to the public
- Task 3: Impact assessment to non-human biota
- Task 4: Training of Ecolego and ERICA to IFE

The present report aims at presenting the work conducted in the frame of Task 1. It includes the identification of the main compartments of the system, the main processes carried out in each compartment, the provision of the concepts of possible model simplifications, and the exposures pathway and endpoints.

The end goal of this task is the preparation of a conceptual model to be implemented in Task 2 & 3 with Ecolego (with the support of AERMOD for the atmospheric dispersion models) and ERICA, respectively.

This report firstly describes the three codes that are going to be used in the frame of this project (Section 2) and it helps understand the further conceptual model development. Then, Section 3 is devoted to the conceptualization of the environmental impact assessment to humans and finally, Section 4 focuses on the environmental impact assessment to non-human biota.

2 Software

This project will use three different codes for assessing the environmental impact assessment of the discharge of radioactive substances from IFE Kjeller plants.

The radiological impact assessment to humans will be estimated using two different software, being the main one Ecolego (see section 2.1) that is used to implement the complete models for the source term to the dose calculation. AERMOD (see section 2.2) will be used to better asses the atmospheric dispersion of the emission plume and its outcome will be used as input data for the model developed in Ecolego.

Radiological assessment to non-human biota will be conducted with the ERICA tool (see section 2.3) that will use the activity concentration in the media estimated with Ecolego as input data.

2.1 Ecolego

The calculation of radiological dose impact assessment to the public due to the emission and discharges from the IFE-Kjeller site, through both water and atmosphere, will be carried out using the software Ecolego.

Ecolego [4] is a versatile software tool mainly used for developing interactive models, as well as carrying out deterministic and probabilistic simulations of dynamic, complex systems evolving over time.

Ecolego was developed by AFRY (formerly FACILIA) with support from the Swedish Radiation Safety Authority (SSM) together with the Norwegian Radiation Protection Authority (NRPA) in 2001. The latest version, Ecolego 8, released in December 2020, gathers an improved user interface, modern solvers for ordinary differential equations and includes different databases and specialized toolboxes.

This code has a user-friendly interface and includes a library of pre-defined models that can be freely download.

This software was initially created to help in the implementation of radioecological models and performing radioecological risk assessments in a MATLAB/Simulink environment [5]. To develop this kind of assessments, Ecolego features a radionuclide toolbox, which contains a database with all nuclide isotopes, together with their decay constants and decay energies. In addition, this toolbox also contains the parent-daughter relationships between a radionuclide and its decay products.

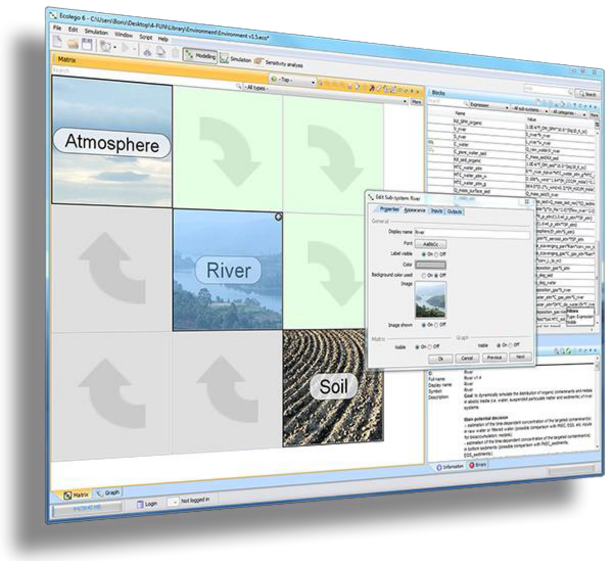

Figure 2-1: *The Graphical User Interface for Ecolego view [4].*

Nowadays, Ecolego is well-known on the global market and has clients throughout the world. Their main business areas are the nuclear industry, mining industry and contaminated lands. Some of the projects to which Ecolego has been applied are the Swedish near-surface and geological repositories, the Finnish geological repository, Fukushima, etc.

In Ecolego, a system is modelled by dividing it into compartments and defining mass fluxes between them. This type of mathematical model is known as compartment model, and it assumes a homogeneous distribution of materials within a compartment, i.e., radionuclides are uniformly mixed in each compartment.

Furthermore, each compartment representing a section of the system can have as many inputs and outputs as the model requires. These fluxes, represented by transfers in the Ecolego interface, correspond to the time-dependent mass influx and outflux of radionuclide. This exchange rate among two different compartments is donor-controlled, so it directly depends on the radionuclide amount present in the compartment from which radionuclide is leaving.

Each compartment has an initial condition setting, which is by default set to zero. To find out radionuclide quantities within each compartment, the difference between the total mass input and output is integrated over time. In addition, when the radionuclide toolbox and the ODE toolbox are used together, Ecolego will automatically calculate the radioactive decay and the ingrowth of possible daughter nuclides.

As the model becomes more detailed, it may become difficult to manage. This can be easily solved by grouping compartments into subsystems. This allows models of complex systems to be easily assembled.

2.2 AERMOD

The AERMOD [6], [7] software is a Gaussian based model widely used by environmental protection agencies to assess the gas emission impact on regional scale. It has been specifically used for predicting the gas emission impact on a city over a long time period. The model provides the concentration distribution for each hour along the studied period and for the whole domain included in the modelled area.

The results can be useful for assessing the impact of the air pollution and thus helping in decision making process. The gas dispersion in the air depends on three main aspects from which input data is required: surface elevation, source emission and weather data.

The AERMOD software comes with a user-friendly Graphical User Interface (GUI) as shown in Figure 2-2. The software package integrates three different software codes for each of the above aspects.

- AERMET: It processes the raw meteorological data to compute the relevant parameters used for model development
- AERMAP: It implements the elevation value to each receptor and source points
- AERMOD: It integrates the result from AERMET and AERMAP and implement the gaussian equation to calculate the concentration of pollutants at ground level

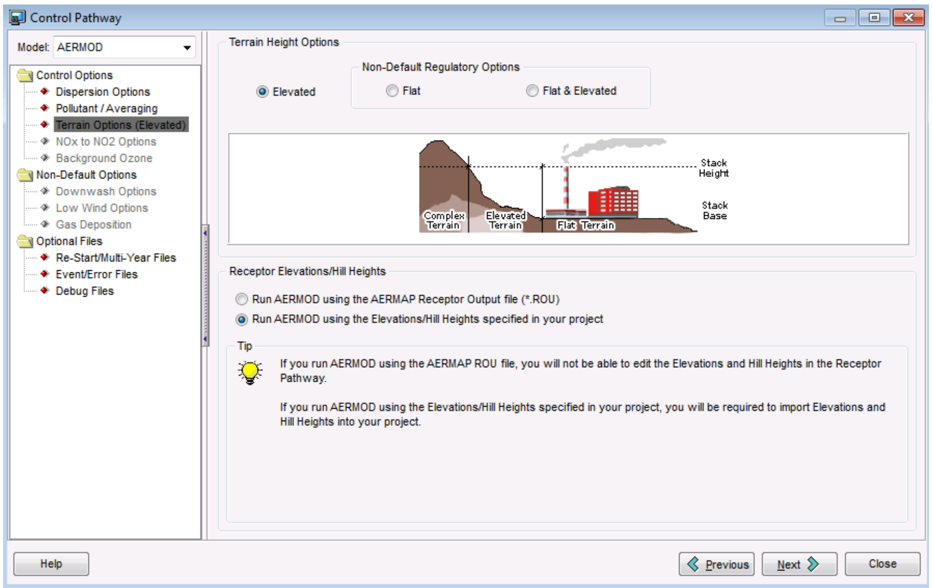

Figure 2-2: *The Graphical User Interface for AERMOD view.*

2.3 ERICA

The radiological assessment for non-human biota associated with aqueous and gaseous emissions of radioactivity from the Kjeller site, has been undertaken using the Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) assessment methodology and associated tool (version 2.0 – build 2.0.185) [8].

ERICA was developed within an EC EURATOM funded project that ran from 2004 until its completion in 2007. The resultant assessment methodology and associated tool (see Figure 2-3) enable the impacts of radioactivity in the environment to be evaluated through the evaluation of absorbed dose rates to a set of reference organisms within a tiered approach. Whilst the ERICA project ended in 2007, the assessment tool has continued to be maintained by an ERICA Consortium, led by the Norwegian Radiation and Nuclear Safety Authority (DSA).

The ERICA assessment tool includes some simple and generic radionuclide transport / dispersion models for aqueous and gaseous emissions. It also allows inclusion of radionuclide activity concentrations in environmental media (e.g., air, soil, water, sediment), whether derived from environmental monitoring data or other modelling assessments.

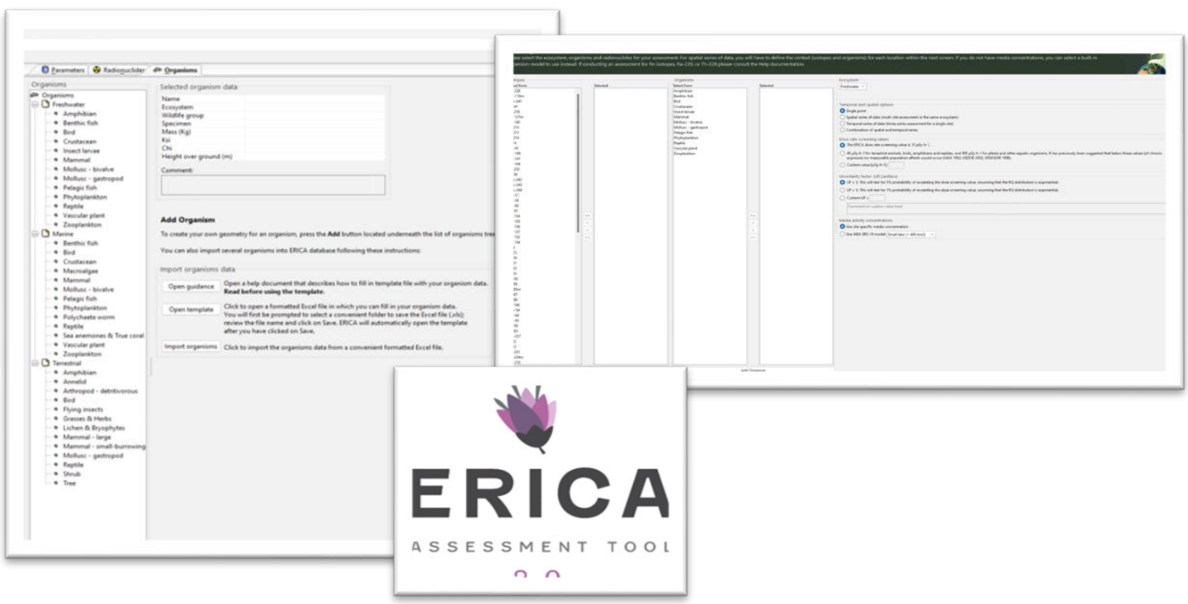

Figure 2-3. *Example ERICA assessment tool parameter pages.*

3 Radiological impact assessment to humans

The International Atomic Energy Agency (IAEA) states that a radiological environmental impact assessment is the estimation of the dose to the public due to the discharge resulting from the operation of the facility or the conduct of the activity [9]. Figure 3-1 shows the steps established by IAEA required to develop and estimate the impact of discharges to the public under the studied conditions, i.e., discharge of air and liquid emissions to the environment from IFE-Kjeller's plants. As a summary of the process, the evaluation starts with the identification and definition of the source term followed by the dispersion of radionuclides in the environment. After identifying the exposure pathways to the public, the environment compartment location relevant for the exposure pathways must be defined. Next, the activity concentrations in each of the selected compartments is conducted to calculate intakes of radionuclides and external irradiation, in combination with relevant data on living habitats and conditions depending on the reference group. Both the intakes of radionuclides and external irradiation, as well as the dosimetric data, is used to estimate the dose to the representative person. Finally, the estimated dose is compared with dose constrains and dose limits.

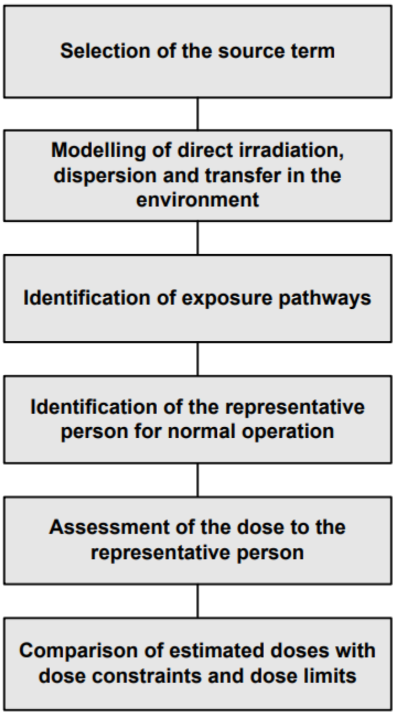

Figure 3-1. *Scheme showing the components of a radiological environmental impact assessment for protection of the public in normal operation [9].*

The present report describes the conceptual model of the steps 1 to 4 and it is conceptualized for the current project specification as detailed in Figure 3-2. An environmental impact assessment will be assessed for each of the radionuclides release pathway to the environment: Gas emission and liquid discharges (see Figure 3-2). This will lead to two different dose estimation to the public, one resulting from gas emissions and the other one, resulting from the liquid discharge to the Nitelva river. In addition, as mentioned before, the same assessment will be conducted per each division. Therefore, 6 different environmental impact assessments based on the same conceptual model will be developed in this project.

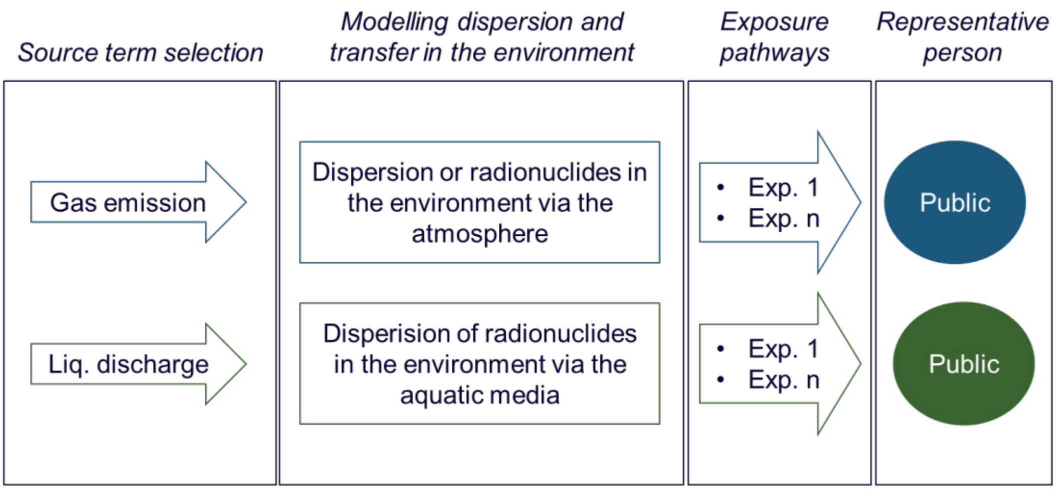

Figure 3-2. *Conceptual model scheme for human dose assessment from IFE Kjeller´s plants discharges.*

Model conceptualization for the radionuclides dispersion in the environment is developed considering that the calculations are conducted using the software tool Ecolego which is based on compartmental model (see section 2.1). The environmental impact will be evaluated for 60 years, which agrees with [9].

In the following lines, each of the items included in Figure 3-2 are described. Firstly, radionuclides release from IFE-Kjeller's plants to the environment are defined (see section 3.1.1 and 3.1.2 for gas emissions and liquid discharges, respectively). This will be the input for the radionuclides transport model that is conceptualized as two box models, one per each release pathway, that are described in section 3.2.

Activity concentration in different environmental media resulting from the transport model, will be used to calculate the dose to the public, being stablished the potential exposure pathways (section 3.3) and the reference group (section 3.4).

3.1 Source term

Two main source terms are identified: (1) the emission of gases to the atmosphere and (2) the discharge of radionuclides in liquid form to the Nitelva river through the NALFA pipeline.

3.1.1 Air emissions

Air emissions includes all radionuclides emitted to the atmosphere in gas or aerosol form through chimneys located in different buildings from the IFE-Kjeller's site. Each IFE's division has different emission points as shown in Figure 3-3.

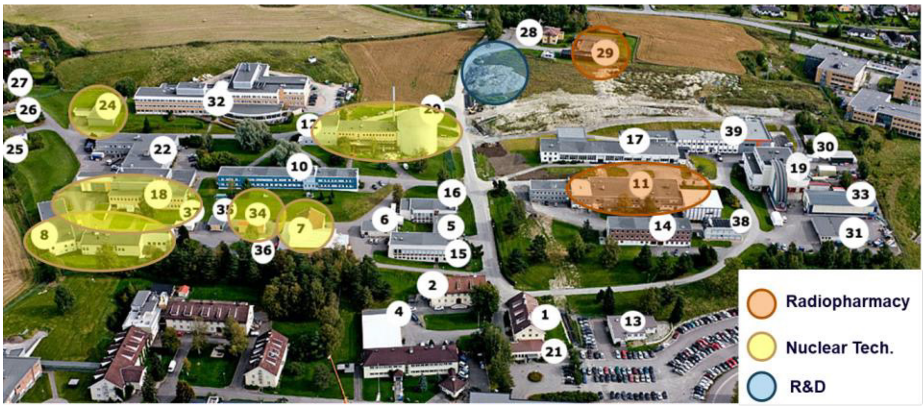

Figure 3-3. *Gas emission point locations per each division.*

The list of radionuclides to be considered it is not fixed yet. Table 3-1 lists the radionuclides that will be considered in the environmental assessment. The final list will be agreed in mid-November 2022. It will contain the radionuclide releases per each division and the annual limit to be authorized, so that the environmental assessment per each division could be developed.

Table 3-1: *Preliminary list of radionuclides considered to be released to the air (contribution from all divisions).*

Radionuclide	Radionuclide	Radionuclide	Radionuclide
H-3	Br-82	Cs-137	Rn-220
F-18	I-131	Lu-177	Rn-219
Ar-41	Ba-133	Ra-223	Th-228
Kr-79	Xe-133	Ac-227	Pb-212
Kr-85	Xe-133m	Th-227	Ra-224
Kr-85m	Xe-135	Ra-227	

The release of most of the radionuclides is not continuous and usually cannot be detected in the monitoring samples collected as part of the monitoring program. To verify to the authorities that the emission limit does not have any significant effect to the public, it will be conducted two different scenarios:

1. Continuous release (annual limit equally distributed along the year)
2. Accidental release (annual limit released in 1 day)

3.1.2 Liquid discharges

Radionuclides released in liquid form originated in each division are discharged together from the Building nº 8 (see Figure 3-3) via the NALFA pipeline to the Nitelva river (Figure 3-4).

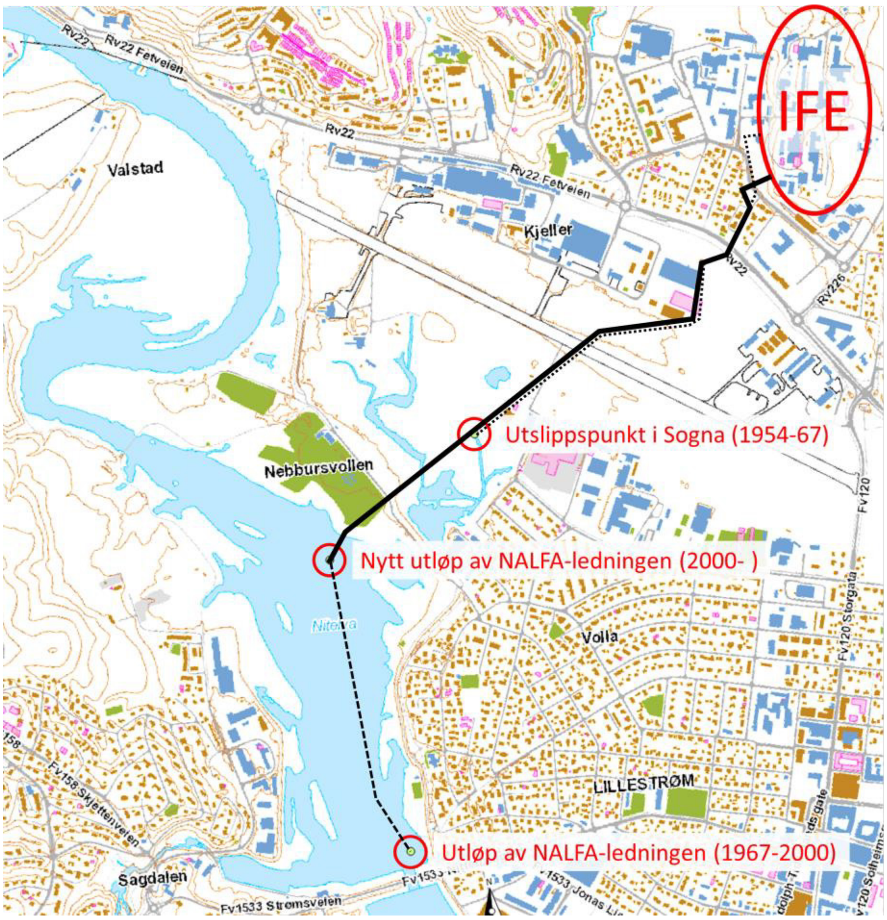

Figure 3-4. *Discharge pipeline from the IFE-Kjeller facilities including the locationnew and the old pipelines [provided by IFE personal communication].*

As in the case of gas releases, the list of radionuclides to be considered it is not fixed yet. Although all radionuclides are released from the same release point, each division should be authorised for a series of radionuclides. Therefore, the environmental assessment will be done for each division considering a list of radionuclides and annual limits specific for each division. The preliminary list of radionuclides to evaluate the impact to humans due to their discharge to the river are presented in Table 4-5.

Table 3-2: *Preliminary list of radionuclides considered to be released to the air (contribution of all divisions).*

Radionuclide	Radionuclide		Radionuclide
H-3	Nb-95	Cs-134	Pu-239
Na-22	Ru-103	Cs-137	Pu-240
Cr-51	Ru-106	Ce-144	Am-241
Mn-54	Ag-110m	Ra123	Cm-243
Co-58	Sb-124	Th-277	Cm-244
Co-60	Sb-125	U-234	Ra-244
Fe-59	I-125	U-235	Th-228
Sr-90	I-131	U-238	Lu-177
Zr-95	Ba-133	Pu-238	Ac-227

The release of all radionuclides is episodic, and the model will consider three releases per year. The amount released in each time will be 1/3 of the annual limit to be authorized.

3.2 Radionuclide dispersion and transport in the environment

This chapter focuses on the description of the conceptual model of the radionuclide transport in the environment as a function of the source term selected. Two different models are developed as, after evaluation, there is no significant connections between both transport pathways. The following transport mechanisms connecting both systems have been not included in the current study:

- Deposition of gaseous radioactivity to the river
- Irrigation of the croplands affected by atmospheric emissions
- Run-off and groundwater flow from the sub-catchment

Therefore, one model is defined for atmospheric emission (section 3.2.1) and a second one for liquid discharges to the Nitelva river (section 3.2.2).

Model description includes both the area of study and the transferences between the environmental compartments. It does not include transferences to living species as it is explained in section 3.3.

The aim of those models is to calculate the activity concentration in the environmental compartments of interest. Those compartments are selected based on the exposure pathways and the reference group definition.

3.2.1 Radionuclide transport in the atmosphere

The atmospheric model is presented in Figure 3-5. It considers that once radionuclides are emitted to the atmosphere, they are dispersed over two different locations: residential area and croplands. Radionuclides in the gaseous form can be deposited on the ground of croplands, further transported to deeper soil layers via bioturbation, percolation or diffusion.

Dispersion of radionuclides in the atmosphere will be conducted with a different code called AERMOD (see section 2.2), and the output will be implemented in Ecolego in terms of air concentration at ground level (Bq/m^3).

Figure 3-5. *Conceptual model for the atmospheric emissions.*

The areas of interest selected for the atmosphere model are presented below.

Residential area (atmosphere)

The closest municipality to IFE-Kjeller's plant that could potentially be exposed to air emissions is Lillestrøm with 89 684 inhabitants [10], located around 2 km south and south-west of the plant (Figure 3-6). As shown in the image there are residents just next to the plant, at about 100 m. The highest concentration calculated by AREMOD in the selected area will be considered in the dose assessment.

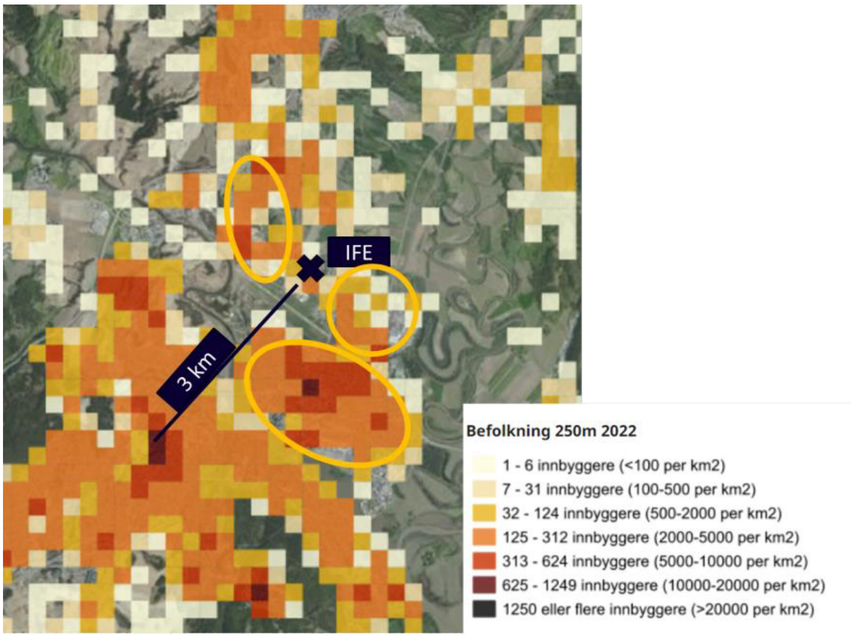

Figure 3-6. *Population density in the proximity of IFE-Kjeller. Circled areas are showing the regions with the highest population density closest to IFE-Kjeller plant* ***[11]****.*

It is important to mention that IFE-Kjeller's plant lies around 20 km from the most densely populated areas of Oslo (Figure 3-7). However, this relatively large distance from the emission point can allow to exclude contamination of Oslo urban area.

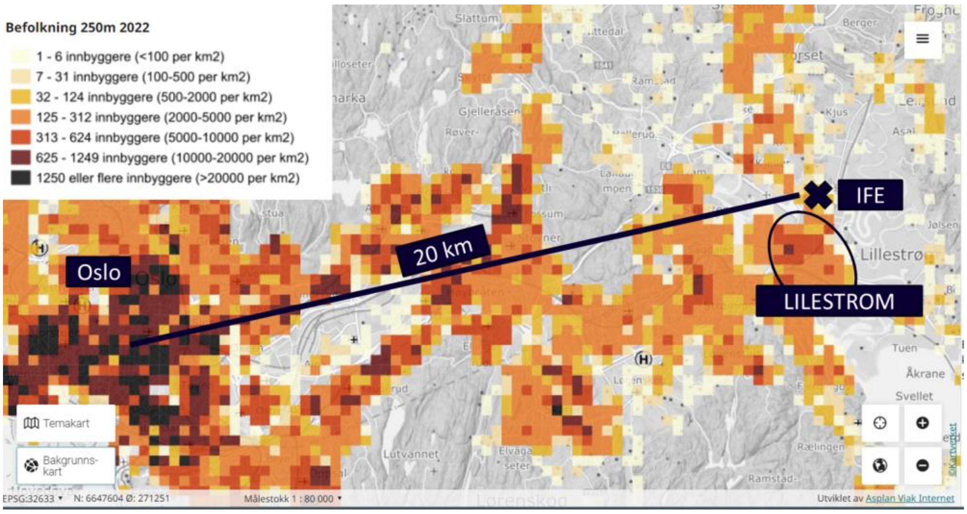

Figure 3-7. *Population density in the Oslo region and distance from IFE-Kjeller's plant* ***[11]****.*

<u>*Croplands area (atmosphere, top soil and deep soil)*</u>

More than 80% of the Lillestrøm municipality are agricultural areas, with soil of high quality and suitable for the grain production [12]. In fact, almost all the areas surrounding the town are used for agriculture.

These fields can be affected by the deposition of radionuclides emitted to the atmosphere. The three areas highlighted in Figure 3-8 are selected as they are the closest agricultural areas from the IFE-Kjeller's plant. They are located from few tenths to few hundred meters north-west, north, and east of the plant.

Therefore, the area of the Ecolego compartment called "Cropland – Top soil 1" will have an area resulting from the sum of the selected areas. The same area will be considered for the compartment "Cropland – Deep soil 1".

It will be considered that the atmospheric concentration in the whole area is homogeneous and the highest concentration calculated by AERMOD within the selected croplands area will be used.

Figure 3-8. *Selected cropland areas in the atmosphere model* ***[13]***.

3.2.2 Transport in surface water

Radionuclides discharged into the Nitelva river through the NALFA pipeline are subject to different physical and chemical processes affecting their transport in the environment (see model represented in Figure 3-9).

The main processes included in the model are:

- Water flow transport: downstream transport (advection)
- Sediment related processes: adsorption/desorption, bioturbation and deposition and resuspension of the sediment
- Diffusion

In addition to the above-mentioned processes, the transfer of radionuclides could occur due to the irrigation of crops using water extracted from the Nitelva river (compartment “River 1”).

Figure 3-9. *Conceptual model of the radionuclide model for the liquid discharge.*

Surface water area (river, top sediment and deep sediment)

The surface water bodies to be considered in this model are the Nitelva river and the Svelle area (see Figure 3-10), which are identified in the model as “River 1” and “River 2”, respectively. The upper part of the Øyeren is not considered in this model as a first attempt, as it is highly probable that the concentration will be diluted enough by the Glomma river. In case it is needed/required by the biota dose assessment, this area will be included in the Ecolego model.

The aquatic zone also considers the river sediments dividing them into two separate compartments called as top sediment and deep sediment.

Note that a third river compartment, named as “River downstream”, is added accounting for the water flux leaving the studied system.

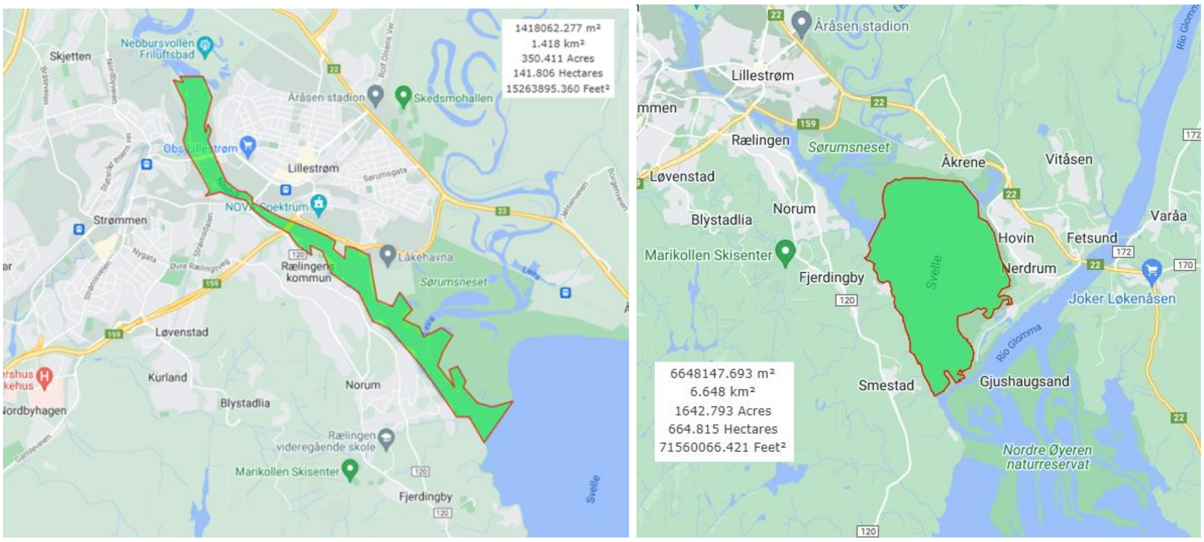

Figure 3-10. *Selected surface water area: (left) Nitelva; (right) Svelle* ***[13]****.*

<u>*Croplands area (top soil and deep soil)*</u>

As previously mentioned, Lillestrøm municipality has an extensive area dedicated to agriculture. The agricultural areas close to the Nitelva river could use water from the river to irrigate the crops. Therefore, two cropland zones close to the studied area of the Nitelva river are selected (see Figure 3-11) and it is assumed that water from the Nitelva river ("River 1" compartment) is always used to irrigate these fields.

As in the previous case, the area of the Ecolego compartment called "Cropland – Top soil 2" will have an area resulting from the sum of the selected areas and the same area will be considered for the compartment "Cropland – Deep soil 1".

It is worth mentioning that these fields are not the same as those selected in the atmospheric model (Figure 3-8) as any of the croplands surrounding the studied area could be affected by both atmospheric emissions and liquid discharges.

Figure 3-11. *Selected cropland areas in the surface water model* ***[13]****.*

3.3 Exposure pathways

The exposure pathways to be selected depends on the radionuclides involved, the habit data, the time spent at the location and other characteristics of the population being considered [9].

Different exposure pathways are selected as a function of the source term evaluated. All potential exposure pathways listed in [9] have been considered but only the ones relevant for the case of study are selected. The justification of those excluded is provided at the end of this chapter.

Exposure pathways for releases to the atmosphere:

- Inhalation of airborne material in an atmospheric plume
- Ingestion of crops
- Inadvertent ingestion of soil and sediments
- External exposure from radionuclides in an atmospheric plume (cloud shine)
- External exposure from radionuclides deposited on the ground (ground shine) and on surfaces

Exposure pathways for releases to the surface water:

- Ingestion of crops
- Ingestion of aquatic food (freshwater or seawater fish, crustaceans, molluscs);
- Inadvertent ingestion of soil and sediments;
- External exposure from radionuclides in water and sediments (i.e. from activities on shores, swimming and fishing).

Radionuclides activity concentration in specific compartments from the atmospheric and surface water models are needed to quantify the dose received via each exposure pathway (Figure 3-12).

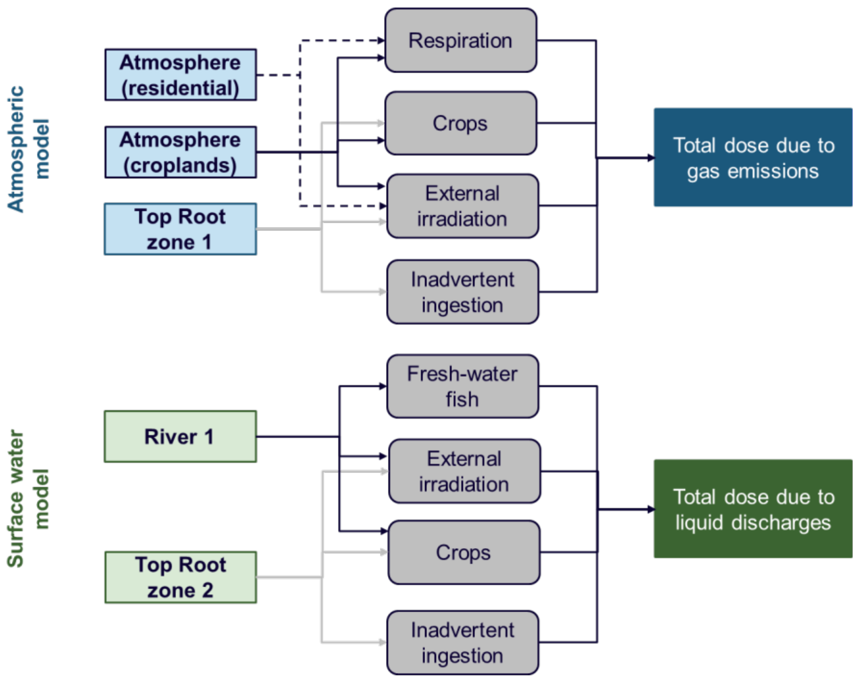

Figure 3-12. *Relevant compartments for the estimation of the dose to public in the atmospheric and surface water model.*

The exposure pathways listed in [9] and excluded from the dose evaluation are listed and justified below. Moreover, after the evaluation of the case of study it is determined that there is no need to add any other exposure pathway.

- Inhalation of resuspended material: particulate radioactive material is not emitted from the IFE-Kjeller's plant and resuspension from the ground would be negligible.

- Ingestion of animal food products (milk, meat, eggs) and ingestion of forest food (wild mushrooms, wild berries, game): Neither farms nor forest environments accessible for the public exists in the emission plume area. Figure 3-13 shows both the location of forests and farms closer to IFE-Kjeller's plant and an approximation of the expected emission plume.

  Before definitely excluding these exposition pathways, the resulting emission plume will be compared with those locations. In case any of them is affected by the emission plume, this exposition pathway will be considered.

- Ingestion of drinking water: water from the Nitelva river is it not used as drinking water.

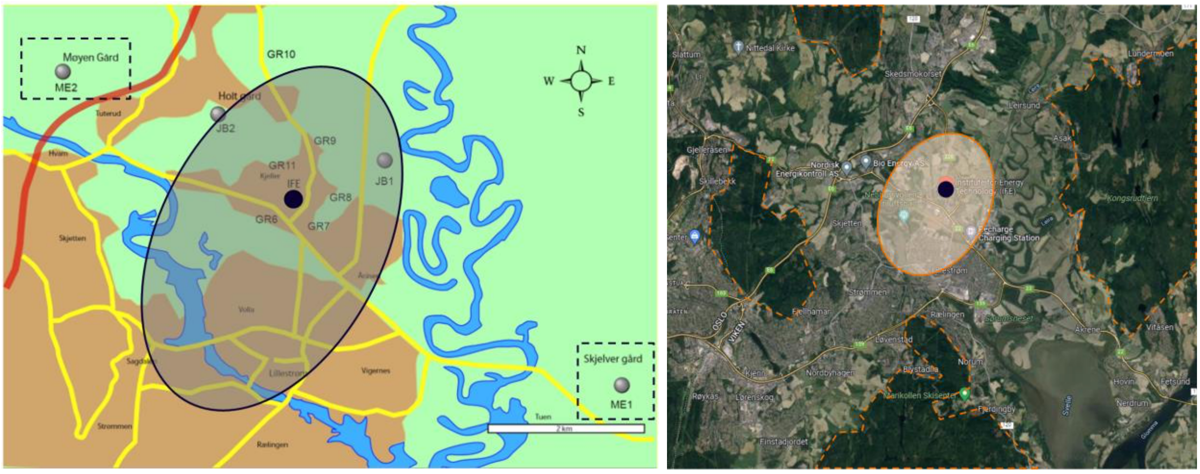

Figure 3-13. *Farmers (left picture, black dashed lines) and forest areas (right picture, orange dashed lines) closest to IFE-Kjeller's plant (black small circle). Approximation of the emission plume is presented in grey and orange-coloured oval areas. Picture are modified from* ***[14]*** *(left) and [2] (right).*

3.4 Reference group

The reference group is based on a farmer living nearby to the IFE-Kjeller's plant. The dose calculation will be assessed for three different age groups being 1 year old infants, 10-year-old children and adults.

The following assumptions, which can be changed when preparing the model if considered necessary to adjust as much as possible to the reality, are considered:

- Living at the residential area more affected by the emission plume
- 4 hours per day working in the cropland area
- Consumption of crops only coming from selected cropland areas
- 1/10 of the fresh-fish consumption comes from the Nitelva river
- 1 h per week swimming in the Nitelva river
- 4 hours per month doing boating activities in the Nitelva river

In case of infant and child, the time spent in the cropland area reduced to 2 h per week and no exposure due to swimming in the river is considered.

4 Radiological impact assessment for non-human biota

The assessment approach planned here is to capitalise on the activity concentrations predicted in environmental media by the Ecolego model as described in Chapter 3.2. This ensures that there is a consistent approach to modelling of radionuclide transport between human and non-human biota assessments.

4.1 Conceptual basis for biota assessment

The radiological assessment for non-human biota associated with aqueous and gaseous emissions of radioactivity to the environment is expressed in terms of a dose rate of micro-Grays per hour (μGy/h). Typically, biota dose rates are assessed relative to a population of a particular species and thus average exposure rates over a geographical area, relevant to the species of interest, are of interest. However, where protected species are present, assessment and protection of individuals in a more localised area may be considered.

Due to the diversity of plants and animals in the environment, it is not feasible to assess exposure of all species, and a sub-set of biota are therefore required. The ERICA assessment tool provides a set of 'reference organisms', which are simplified geometric representations (spheres and ellipsoids) of different types of biota (e.g., fish, bird etc.). In this, organisms are described in terms of length (L), width (W), height (H) and mass as shown in Figure 4-1.

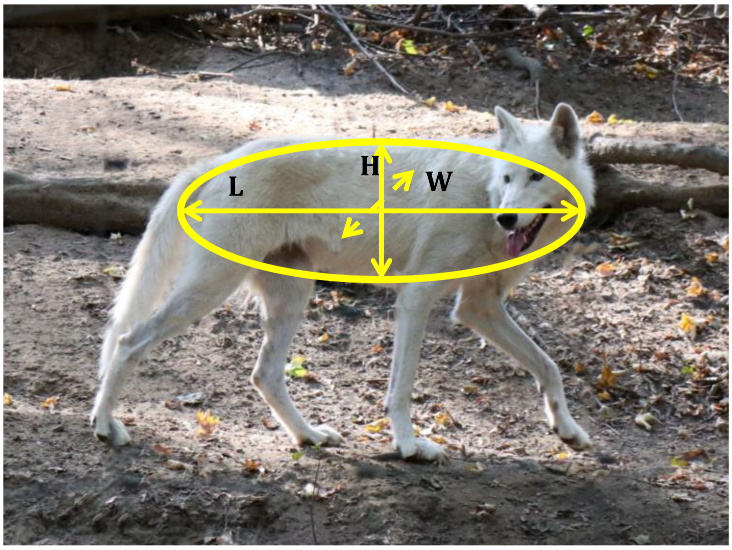

Figure 4-1: *Example of the geometric representation of an organism.*

Reference organisms also have generalised occupancy habits within the ecosystems they inhabit (i.e., their position relative to environmental media, namely air, soil, sediment and/or water). As illustrated in Figure 4-2, biota can either be within soil or on/above the soil surface in terrestrial systems, whereas in aquatic systems, biota can be present within sediment, on sediment, within water or on the water surface.

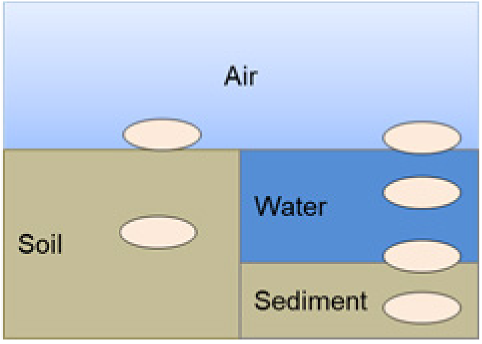

Figure 4-2: *Simplified representation of terrestrial (left) and aquatic (right) ecosystems and possible occupancies of reference organisms relative to environmental media.*

The reference organisms were selected to represent typical types of plant and animal commonly found in terrestrial, freshwater and marine ecosystems throughout Europe. They are not intended as direct representations of any particular species. Relevant reference organisms for the current assessment are shown in Table 4-1.

Table 4-1: *ERICA Reference Organisms for terrestrial and freshwater ecosystems.*

Freshwater	Terrestrial
Amphibian	Amphibian
Benthic fish	Annelid
Bird	Arthropod - detritivorous
Crustacean	Bird
Insect larvae	Flying insects
Mammal	Grasses and herbs
Mollusc – bivalve	Lichens and bryophytes
Mollusc – gastropod	Mammal - large
Pelagic fish	Mammal – small burrowing
Phytoplankton	Mollusc - gastropod
Reptile	Reptile
Vascular Plant	Shrub
Zooplankton	Tree

The ERICA reference organisms encompass the International Commission on Radiological Protection (ICRP) Reference Animals and Plants (RAP). Terrestrial and freshwater RAPs are the bee (flying insect), deer (large mammal), duck (bird), earthworm (annelid), frog (amphibian), pine tree (tree), rat (small mammal), salmonid (pelagic fish) and wild grass (grasses and herbs). The ICRP use of RAPs is comparable to the radiation protection concept of 'Reference Man'. A RAP is defined as: 'a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism.' It is acknowledged that the RAPs may not be the direct objects of protection per se, however their consideration allows different levels of organism radiosensitivity to be considered.

ICRP Publication 124 suggests using 'representative species' for site-specific assessment" [15]. That is, consideration of animal and plant species specific to a particular site. In most instances, site-specific species can be adequately covered by the ERICA reference organisms (inclusive of the ICRP RAPs) where a particular species is 'mapped' to a particular reference organism. However, in some instances new organisms with associated parameters may need to be added.

Unlike radiation protection of humans, dose 'limits' are not applied to protection of biota. Instead, biota exposures are considered relative to screening values and ICRP 'Derived Consideration Reference Levels' (DCRLs).

DCRLs are available for each of the 12 ICRP RAPs and are 'order of magnitude' bands of dose rates that have been set at a level within which there is likely to be some chance of the occurrence of deleterious effects. The DCRLs are not intended to be applied as limits, but rather as points of reference to "inform on the appropriate level of effort that should be expended on environmental protection, dependent on the overall management objectives, the exposure situation, the actual fauna and flora present, and the numbers of individuals thus exposed" [ICRP, 2014]. For planned exposure situations[1], the ICRP position is that annually averaged exposures should not exceed the lower band of DCRL for each RAP [15].

In addition to the ICRP DCRLs, ERICA provides an incremental screening value of 10 µGy/h. The screening value is applicable to all organisms across all ecosystems. The screening value

[1] That is, where a situation of exposure has arisen from a planned operation, i.e., an authorised discharge.

was derived statistically from radiation effects data and is set at a level below which deleterious effects on non-human biota are unlikely to occur and is broadly consistent with the DCRLs for the most radiosensitive RAPs.

4.2 Natural environments in the region of Kjeller facility

4.2.1 Approach to identifying representative species for assessment

Species that are representative of the local environments around the Kjeller site have been identified using a tiered approach.

Initially, species associated with important and protected habitats in the terrestrial environment around Kjeller and downstream of the liquid effluent discharge point in the Nitelva River were identified using the interactive map available from Environment Norway [16]. Results are presented in Figure 4-3. Management areas for carnivores were also identified. For each identified area, Environment Norway information supporting the designation was reviewed and species associated with the designations were identified.

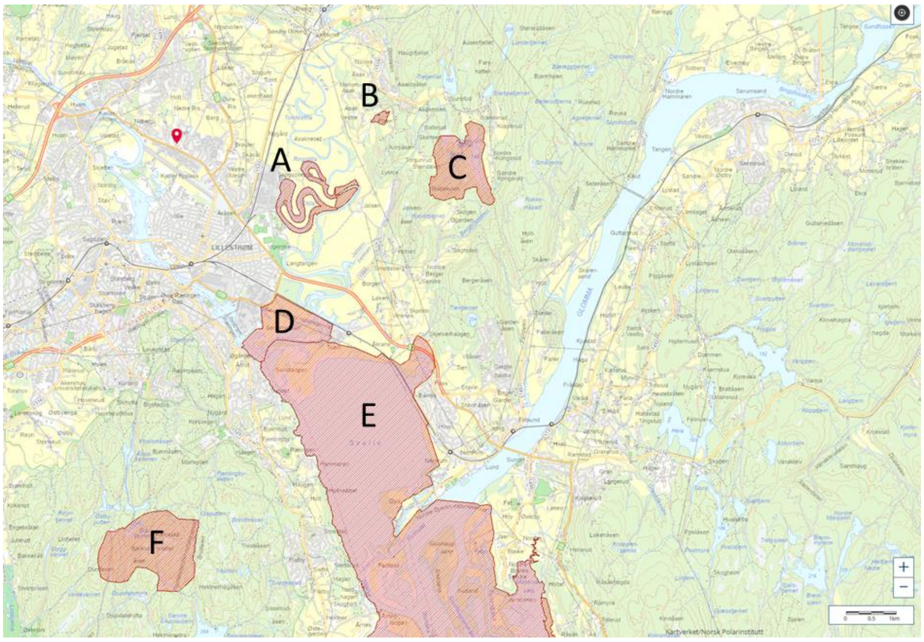

Figure 4-3: *Protected areas in the vicinity of the Kjeller* ***[16]****. A – Stilla og Brauterstilla; B – Flaen; C – Kongsrudtjern; D – Sørumsneset; E – Nordre Øyeren; F – Ramstadslottet.*

In addition to researching species associated with designated areas, recorded observations of endangered, vulnerable and threatened species in the area of Lillestrøm Creek, which encompasses the area around Kjeller and the municipality of Lillestrøm, were identified using the interactive Norway's Species Map Service from the Norwegian Biodiversity Information Centre [17]. A list of observations for the period 2000 to 2022 was generated using the interactive map. The observations during this period are illustrated in Figure 4-4.

Finally, the same interactive map for Lillestrøm Creek was used to list additional species that are not classified as endangered, vulnerable or threatened, but generally associated with the terrestrial and freshwater environments around the Kjeller site, based on recorded observations. Some of the most commonly observed species were then selected as representative species for assessment, focussing on plant and animal categories (based on the categories of freshwater and terrestrial biota within the ERICA assessment tool) with no or few species identified based on the previous review stages, to ensure key species groups and trophic levels within broad terrestrial and aquatic food webs were represented.

General descriptions of freshwater and terrestrial habitats are provided below, along with the representative species selected for assessment.

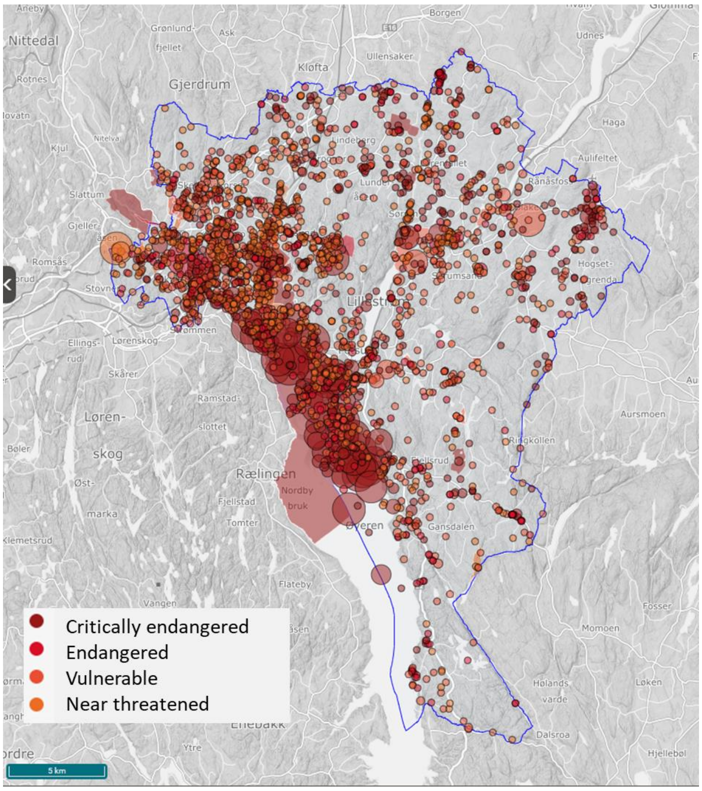

Figure 4-4: *Observations of endangered, vulnerable and threatened (red-list) species in the area of Lillestrøm Creek in the period 2000 – 2022* ***[17]****.*

4.2.2 Aquatic habitats and representative species

The Nitelva River is classed as an important stream habitat within an intensively managed agricultural landscape (Designation BN00016174 [18]) and as a species functional area (Designation BA00046949 [19]) for game. The habitat comprises the Nitelva River and the associated riparian zone. Over 70 plant species have been recorded, including sedges and grasses and floating-leaf plants. The red-listed species fen violet (*Viola stagnina*) and meadow starwort (*Stellaria* palustris) are present [18].

The Nitelva River is also designated as a species functional area for overwintering and migratory birds including mallard (*Anas platyrhynchos*), and greater scaup (*Aythya marila*), which is a vulnerable red-listed species [19]. Common frog (*Rana temporaria*) and moor frog (*Rana arvalis*) are also associated with the area.

The river flows in a south easterly direction to Lake Øyeren. On passing Lillestrøm, the river river flows through the Sørumsneset nature reserve (Designation VV00000638), a wetland of particular importance for its rich bird life [20]. Here, the river meets with the River Leira before flowing to the Svelle mudflat area, classed as an important habitat for vascular plants, game, fish and clams (Designation BN00071129 [21]). At the base of the Svelle mudflat, the river combines with the River Glomma before reaching Lake Øyeren, which is northern Europe's largest inland delta and Norway's most species-rich lake [22]. Together, the Svelle and northern area of lake Øyeren form the Nordre Øyeren nature reserve, which is classified as a wetland of international importance under the Ramsar Convention[2] (Figure 4-5).

[2] The Convention on Wetlands (Ramsar Convention) is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

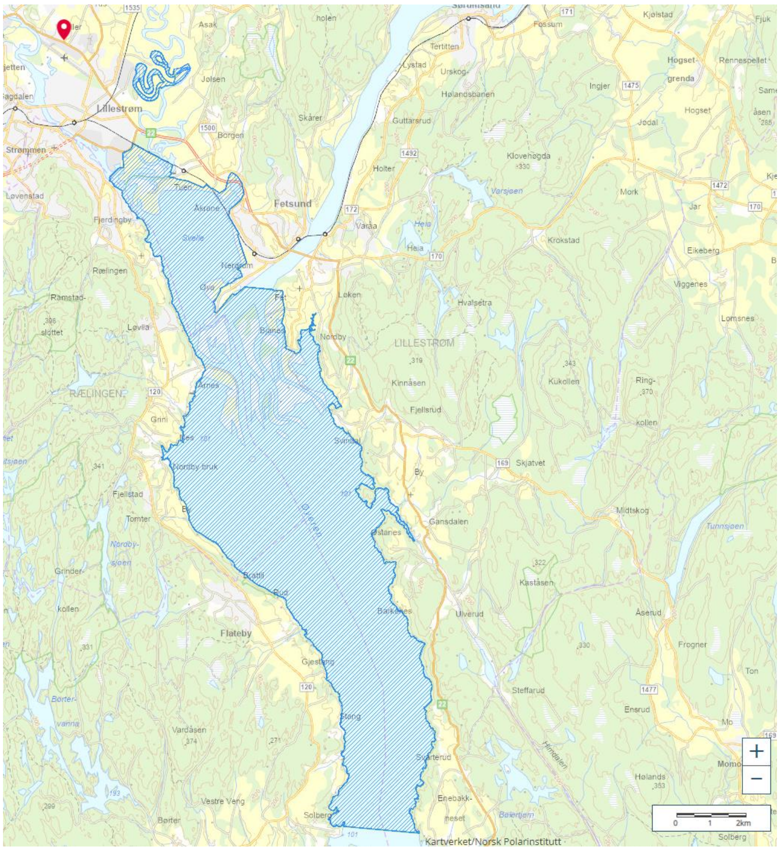

Figure 4-5: *Location of the Norde Øyeren Ramsar Site* ***[16]****.*

The Nordre Øyeren nature reserve includes low-lying islands and land adjacent to Lake Øyeren and represents a rich and complex wetland system of branched rivers, swamps, lagoons, islands and canals [23]. The area provides an important wetland habitat for a wide range of bird species, including the red-listed species Eurasian coot (*Fulica atra*), common moorhen (*Gallinula chloropus*), Eurasian curlew (*Numenius arquata*), northern lapwing (*Vanellus vanellus*) and black-headed gull (*Chroicocephalus ridibundus*) [24].

The water level of Lake Øyeren varies seasonally, giving rise to mudflats in both spring and autumn that provide an important feeding resource for migratory birds, such as greylag goose (*Anser anser*) and the area, together with the lower Nitelva River, provides the most important wintering area for whooper swans (*Cygnus cygnus*) in Norway. The site also supports large populations of fish and benthic organisms. Species associated with the area include northern pike (*Esox lucius*), common perch (*Perca fluviatilis*), duck mussel (*Anodonta anatina*), depressed river mussel (Pseudanodonta complanata), rams horn snail (*Gyraulus acronicus*) and European crayfish (Astacus astacus). The semi-aquatic species European beaver (*Castor fiber*) and European water vole (*Arvicola amphibius*) are also associated with the area.

Representative species associated with the freshwater habitats of the area are listed in Table 4-2 and each species mapped onto the relevant ERICA reference organism.

Table 4-2: *Freshwater representative species selected for assessment and their mapping to ERICA reference organisms. (Note on Red-list status: EN – endangered; VU – vulnerable; NT – near threatened; LC – least concern)*

ERICA reference organism	Representative species	Latin name	Red-list status
Amphibian	Common frog	*Rana temporaria*	LC
	Moor frog	*Rana arvalis*	VU
	Northern crested newt	*Triturus cristatus*	NT
Benthic fish	Common rudd	*Scardinius erythrophthalmus*	LC
	Common bream	*Abramis brama*	LC
	Eurasian ruffe	*Gymnocephalus cernuus*	LC
Bird	Eurasian coot	*Fulica atra*	VU
	Mallard	*Anas platyrhynchos*	LC
	Greater scaup	*Aythya marila*	EN
	Common moorhen	*Gallinula chloropus*	VU
	Greylag goose	*Anser anser*	LC
Crustacean	Water sowbug	*Asellus aquaticus*	LC
Insect larvae	Dragonflies	*Sympetrum spp.*	LC
	Caddis fly	*Lype reducta*	NT
Mammal	Beaver	*Castor fiber*	LC
Bivalve mollusc	Duck mussel	*Anodonta anatina*	LC
	Depressed river mussel	*Pseudanodonta complanata*	LC
Gastropod mollusc	Rams horn snail	*Gyraulus acronicus*	LC
Pelagic fish	European perch	*Perca fluviatilis*	LC
	Common roach	*Rutilus rutilus*	LC
	Northern pike	*Esox lucius*	LC
Phytoplankton	Green algae	*Microspora amoena* *Ulothrix zonata*	LC
Reptile	*Not applicable*		
Vascular plant	Stonewort	*Nitella mucronata*	NT
	Water pygmyweed	*Crassula aquatica*	VU
	Mudwort	*Elatine triandra*	EN
	Lesser pondweed	*Potamogeton pusillus*	EN

ERICA reference organism	Representative species	Latin name	Red-list status
Zooplankton	Water flea	*Daphnia spp.*	LC
User-defined representative species			
Large crustacean	European crayfish	*Astacus astacus*	EN
Large bird	Whooper swan	*Cygnus cygnus*	LC
	Greylag goose	*Anser anser*	LC
Small mammal	European water vole	*Arvicola amphibius*	LC

4.2.3 Terrestrial habitats and representative species

The terrestrial areas of the site are comprised of coniferous and deciduous forests, grasslands and meadows that support a rich plant and animal diversity, including the red-listed species almond willow (*Salix triandra*) and northern goshawk (*Accipiter gentilis*) [25]. Northern Lake Øyeren also falls within management areas for lynx (*Lynx lynx*) and grey wolf (*Canis lupus*), as illustrated in Figure 4-6.

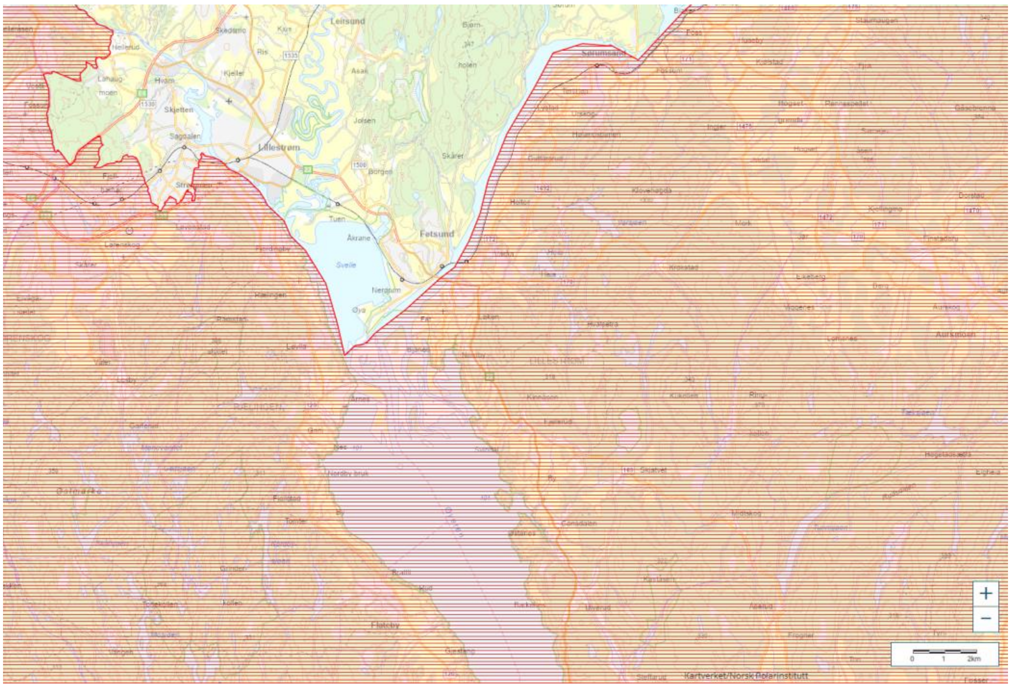

Figure 4-6: *Management area for wolf* ***[16]***.

Two forests located approximately 4-5 km to the east of Kjeller are designated as protected areas (marked B and C in Figure 4-3). These are the Flaen and Kongsrudtjern nature reserves. Flaen nature reserve is a swamp and spring forest that is important for biodiversity. The forest is dominated by gray alder and is species-rich in terms of birds [26]. The Kongsrudtjern nature reserve is a coniferous forest area with diverse plant species, including several important lichen and moss species. There are also valuable amphibian and insect fauna present, including several endangered and vulnerable species. Marsh areas are also present.

In addition to protected forest areas, wetlands and riparian zones associated with the Nordre Øyeren and Sørumsneset nature reserves provide habitats for a wide range of terrestrial species. Large parts of the nature reserve are associated with forest and meadow areas. Willow (*Salix* spp) and birch dominate forest areas. The meadows provide habitat for a wide range of plant species, including red-listed species such as nodding bur-marigold (*Bidens cernua*) and meadow starwort (*Stellaria palustris*) and for wading birds that feed on the mudflats, including Eurasian curlew (*N. arquata*), northern lapwing (*V. vanellus*) and black-headed gull (*Chroicocephalus ridibundus*). Semi-aquatic species water vole (*A. amphibius*) and European beaver (*C. fiber*) are also associated with these areas.

Other species identified with the terrestrial environment around Kjeller include roe deer (*Capreolus capreolus*), moose (*Alces alces*), long-eared owl (*Asio otus*) and white-backed woodpecker (*Dendrocopos leucotos*). Several red-listed bumblebees are also present, including great yellow bumblebee (*Bombus distinguendus*) and brown-banded carder bee (*B. humilis*) [27].

Other species identified with the area that inhabit terrestrial habitats, as identified from the interactive map service of the Norwegian Biodiversity Information Centre [17], include mammals such as red fox (*Vulpes vulpes*), European badger (*Meles meles*), European hedgehog (*Erinaceus europaeus*), and reptiles such as grass snake (*Natrix natrix*) and common lizard (*Zootoca vivipara*). Several amphibian species have also been identified in the area that can be associated with both terrestrial and freshwater habitats, including common frog (*R. temporaria*) and moor frog (*R. arvalis*).

Representative species associated with the terrestrial habitats of the area are listed in Table 4-3 and each species mapped onto the relevant ERICA reference organism.

Table 4-3: *Terrestrial representative species selected for assessment and mapping to ERICA reference organisms. (Note on Red-list status: EN – endangered; VU – vulnerable; NT – near threatened; LC – least concern)*

ERICA reference organism	Representative species	Latin name	Red-list status
Amphibian	Common frog	*Rana temporaria*	LC
	Moor frog	*Rana arvalis*	VU
	Northern crested newt	*Triturus cristatus*	NT
Annelid	Earthworms	*Lumbricus terrestria*	LC
Arthropod	Beetle	*Ampedus sanguinolentus*	EN
	Beetle	*Lordithon pulchellus*	VU
	Blister beetle	*Apalus bimaculatus*	NT
Bird	Northern goshawk	*Accipiter gentilis*	VU
	Eurasian curlew	*Numenius arquata*	EN
	Northern lapwing	*Vanellus vanellus*	CR
	Black-headed gull	*Chroicocephalus ridibundus*	CR
	Long-eared owl	*Asio otus*	LC
	White-backed woodpecker	*Dendrocopos leucotos*	LC
Flying insect	Great yellow bumblebee	*Bombus distinguendus*	EN
	Brown-banded carder bee	*Bombus humilis*	LC
	Dragonflies	*Sympetrum spp.*	LC
	Caddis fly	*Lype reducta*	NT
Grasses & herbs	Nodding bur-marigold	*Bidens cernua*	EN
	Meadow starwort	*Stellaria palustris*	VU
	Creeping lady's-tresses	*Goodyera repens*	NT
	Meadow oat-grass	*Avenula pratensis*	NT
Lichen & bryophyte	Feather flat moss	*Neckera pennata*	VU
	New England bryhnia moss	*Brachythecium novae-angliae*	NT
	Campylium moss	*Pseudocampylium radicale*	EN
	Foliose lichen	*Physcia tenella*	LC
	Witch's-hair lichen	*Alectoria sarmentosa*	NT
Mammal (large)	Moose	*Alces alces*	LC
Mammal (small burrowing)	Water vole	*Arvicola amphibius*	LC
	European hedgehog	*Erinaceus europaeus*	NT

ERICA reference organism	Representative species	Latin name	Red-list status
	Yellow-necked mouse	*Apodemus flavicollis*	LC
	Field vole	*Microtus agrestis*	LC
Gastropod mollusc	Copse snail	*Arianta arbustorum*	LC
	Door snail	*Macrogastra ventricosa*	NT
Reptile	Grass snake	*Natrix natrix*	LC
Shrub	Almond willow	*Salix triandra*	NT
	Common juniper	*Juniperus communis*	LC
Tree	Almond willow	*Salix triandra*	NT
	Silver birch	*Betula pendula pendula*	LC
	Gray alder	*Alnus incana*	LC
	European ash	*Fraxinus excelsior*	EN
	Norway spruce	*Picea abies*	LC
User-defined representative species			
Mammal (medium)	Lynx	*Lynx lynx*	EN
	Grey wolf	*Canis lupus*	CR
	Roe deer	*Capreolus capreolus*	LC
Mammal – large burrowing	Red fox	*Vulpes vulpes*	LC
	European badger	*Meles meles*	LC
Semi-aquatic mammal	European beaver	*Castor fiber*	LC
Reptile (small)	Common lizard	*Zootoca vivipara*	LC

4.3 Calculation of biota exposure

The approach to the calculation of non-human biota exposure is described below.

4.3.1 Tiered Assessment Approach

ERICA provides three tiers of assessment:

- **Tier 1** is a simple and highly conservative screening assessment using maximum activity concentrations in environmental media as input. These are compared against Environmental Media Concentration Limits (EMCL) that have been derived for each radionuclide-reference organism combination by back calculating the environmental concentration of each radionuclide that would give rise to a dose rate consistent with a screening dose rate value. The EMCL for the most limiting reference organism within a given ecosystem is applied. Tier 1 is limited to the reference organisms and radionuclides included as defaults within the assessment tool.

- **Tier 2** is a less conservative screening assessment with a greater user-interface that enables a more tailored assessment to be undertaken, including defining representative species in support of site-specific assessments and/or the addition of radionuclides that are not included by default. The habits of organisms (e.g., their position relative to environmental media) and assessment parameters such as concentration ratio (CR) and water-sediment partition coefficients (Kd) can also be revised for a more site-specific application. Tier 2 is recommended as the entry point for assessments where user-defined representative species are to be assessed or where radionuclides of interest are not included by default.
- **Tier 3** is intended for use in situations where results of tier 2 assessments, following any appropriate assessment refinement, are above the screening value. It provides the basis for detailed assessments to be undertaken probabilistically using sensitivity analysis. No screening dose rate is applied; rather, output should be compared against available effects data in order to inform judgement on the likely consequences of the calculated dose rates for the organisms of interest. Note, tiers 1 and 3 cannot be applied to noble gases or radon (Rn-222) and thoron (Rn-220).

A screening assessment has been undertaken using an MS Excel tool developed by the Environment Agency of England, the Initial Radiological Assessment Tool (IRAT). This has indicated that biota dose rates are likely to be very low, well below the ERICA incremental screening dose rate of 10 µGy/h. As such, a tier 3 assessment is not justified and equally is not appropriate where noble gases and radon and thoron need to be considered. However, as user-defined representative species are to be assessed, a tier 2 assessment is needed. The dosimetry applied in this is described below.

4.3.2 ERICA Dosimetry

Version 2.0 of ERICA was released in November 2021 and presents the most up to date version of the tool. It includes:

- New dosimetry including the implementation of the ICRP Publication 136 [28] for the calculation of dose coefficients (DCs) for user define organisms and a new approach for the calculation of the dose contribution from short-lived progeny in a decay chain.

- Inclusion of noble gases and Rn-222 and Rn-220, including dose coefficients for external radiation from immersion in air and internal alpha radiation, the calculations for which are available at tier 2 only.

Updated CRs and K_d values and various other functional enhancements.

4.3.2.1 Calculation of dose-rates

The following description of how dose-rates are calculated in ERICA is based on the ERICA Version 2.0 helpfile (Last Updated: 28 October 2021).

The geometric representation of organisms provides the basis for internal and external DCs to be calculated, specific to each organism and radionuclide and taking into account the organisms position in relation to environmental media (soil, air, sediment, water). The DCs are defined as the internal or external absorbed dose rates in µGy/h per activity concentration in an organism (Bq/kg) or environmental medium (Bq/kg in soil or sediment, Bq/m^3 in air or Bq/L water).

Internal exposure is calculated in relation to the average activity concentrations of radionuclides in environmental media and a CR is applied to estimate the activity concentration in the organism, assuming homogenous distribution, relative to that in environmental media.

Internal DCs are then applied to convert the average radionuclide concentrations within the body of the reference organism to an internal absorbed dose rate. ERICA provides generic CRs for all default reference organisms and radionuclides. By preference, empirical CR data have been incorporated, with data gaps being necessarily addressed through the application of analogue approaches.

External absorbed dose rates for a reference organism are calculated from the external DCs and the average concentration in the environmental media they inhabit (air and soil in terrestrial ecosystems and water and sediment in aquatic ecosystems). For example, a small burrowing mammal may spend a proportion of time within soil and a proportion of time in the above-soil compartment, which is expressed through the use of occupancy factors. For aquatic environments, a K_d is applied to account for the partitioning of radionuclides between sediment and water and hence the external dose from different parts of the aquatic ecosystem.

For terrestrial biota the environmental media is the soil, except where noble gases or H-3 or C-14 are considered, where the environmental media is the air. For aquatic biota the environmental media is the water or sediment.

4.3.2.2 Internal dose-rates from radon and thoron (terrestrial environment)

Unlike other noble gases (Ar, Kr and Xe) where ERICA only accounts for the cloud/plume immersion dose rate, Rn-222 and Rn-220 assessments also need to account for the contribution of these radionuclides (and more importantly their decay products) to dose rates arising from inhalation and deposition in the lung. ERICA considers this as a component of 'internal' contribution to exposure and use values based on the methodology of Vives i Batlle et al. (2017) [29].

It is important to note that the units for internal DCs for Rn-222 and Rn-220 differ from the standard internal DCs for all other radionuclides. Whereas the standard ERICA internal DCs relate to the activity concentration in the (whole) body of the plant or animal, and thus have units of μGy/h per Bq/kg f.w., Rn-222 and Rn-220 are aggregated DCs and relate (the internal dose-rate) directly to the concentrations, and thus have units of μGy/h per Bq/m^3.

Vives I Batlle et al. [29] also note that alpha particles contribute about 95% of the total emitted energy of radon progeny. For the sake of simplicity and of conservatism, ERICA assumes that alpha particles contribute 100% of the total emitted energy of radon progeny. The same assumption has been made for both Rn-222 and Rn-220.

The allometric equations used in derivation of animal Rn-222 and Rn-220 DCs are relevant specifically for mammals, however, they have been included in the ERICA tool and extrapolated to terrestrial invertebrate reference organisms, namely annelid, arthropod - detrivorous, flying insects and mollusc – gastropod. The use of these DCs for non-mammals should therefore be considered as illustrative only. For in-soil organisms, the Rn-222 or Rn-220 activity concentrations in soil air are assumed to be the same as that in air above the soil surface.

Due to uncertainties in the application of inhalation dose rate dosimetry to plants, no DCs are available in ERICA for terrestrial plants. Also, inhalation DCs for other isotopes of radon (e.g., Rn-219) are not available and these therefore have to be assessed as either Rn-222 or Rn-220.

4.3.3 Radionuclides to include in assessment

The radionuclides that are anticipated to need inclusion in the assessment are discussed below. The ERICA assessment tool (version 2.0) includes a library of default radionuclides where the DC values incorporate short-lived decay products with a half-life less than 10-days.

Note, where longer-lived decay products are relevant, they need to be assessed separately and manually included in the assessment.

The ERICA library of default radionuclides excludes Na-22, Fe-59, Lu-177, Ra-223 and Ac-227. However, ERICA includes all the underpinning parameters to calculate the dosimetry for virtually any radionuclide, including those listed here (except Kr-79 and Rn-219). These non-default radionuclides have to be included using the 'add radionuclide' function. Note, the DCs associated with these non-default radionuclides exclude any decay products and hence where relevant, these need to be assessed separately and manually included in the assessment.

Krypton-79 and Rn-219 are not available and here analogues will need to be used.

4.3.3.1 Aqueous discharges

Radionuclides to be considered in aqueous discharges are detailed in Table 4-4.

Table 4-4: *Radionuclides to be considered for aqueous discharges*

Radionuclide	Included in ERICA	Default decay chain included in assessment of parent	Decay chains that will need to be included[3]
H-3 (HTO)	Default	N/A	N/A
Na-22	Non-default	N/A	N/A
Cr-51	Default	N/A	N/A
Mn-54	Default	N/A	N/A
Co-58	Default	N/A	N/A
Co-60	Default	N/A	N/A
Fe-59	Non-default	N/A	N/A
Zn-65	Default	N/A	N/A
Sr-90	Default	Y-90 (2.66 d)	N/A
Zr-95	Default	N/A	Nb-95 (34.99 d)
Nb-95	Default	N/A	N/A

[3] Broadly assumed that decay products take seven half-lives to achieve equilibrium with parent. Hence a precautionary assessment that over the course of several decades of operation, radionuclides with a half-life less than 10 yr could be in equilibrium with radionuclides discharged in near-term emissions

Radionuclide	Included in ERICA	Default decay chain included in assessment of parent	Decay chains that will need to be included[3]
Ru-103	Default	N/A	N/A
Ru-106	Default	Rh-106 (30.07 s)	N/A
Ag-110m	Default	N/A	N/A
Sb-124	Default	N/A	N/A
Sb-125	Default	N/A	N/A
I-125	Default	N/A	N/A
I-131	Default	N/A	N/A
Ba-133	Default	N/A	N/A
Cs-134	Default	N/A	N/A (decay product Xe-134 ignored due to long half-life)
Cs-137	Default	Ba-137m (2.55 m)	N/A
Ce-144	Default	N/A	N/A
Lu-177	Non-default	N/A	N/A
Ra-223	Non-default	N/A	Rn-219* (3.96 s), Po-215 (1.78 ms), Pb-211 (36.17 m), Bi-211 (2.14 m), Tl-207 (4.77 m)
Ra-224	Default	Po-216 (145 ms), Pb-212 (10.64 hr), Bi-212 (1.01 h), Po-212 (299 ns), Tl-208 (3.05 m)	N/A
Ac-227	Non-default	N/A	Th-227 (18.68 d), Ra-223 (11.43 d), Rn-219* (3.96 s), Po-215 (1.78 ms), Pb-211 (36.17 m), Bi-211 (2.14 m), Tl-207 (4.77 m)
Th-227	Default	N/A	Ra-223 (11.43 d), Rn-219* (3.96 s), Po-215 (1.78 ms), Pb-211 (36.17 m), Bi-211 (2.14 m), Tl-207 (4.77 m)
Th-228	Default	Ra-224 (3.63 d), Po-216 (145 ms), Pb-212 (10.64 hr), Bi-212 (1.01 h), Po-212 (299 ns), Tl-208 (3.05 m)	N/A
U-234+	Default	N/A	N/A (decay product Th-230 ignored due to long half-life)
U-235+	Default	Th-231	N/A (decay product Pa-231 ignored due to long half-life)
U-238+	Default	N/A	Th-234 (which in ERICA includes Pa-234)
Pu-238	Default	N/A	N/A (decay product U-234 ignored due to long half-life)

Radionuclide	Included in ERICA	Default decay chain included in assessment of parent	Decay chains that will need to be included[3]
Pu-239	Default	N/A	N/A (decay product U-235 ignored due to long half-life)
Pu-240	Default	N/A	N/A (decay product U-236 ignored due to long half-life)
Am-241	Default	N/A	N/A (decay product Np-237 ignored due to long half-life)
Cm-243	Default	N/A	N/A (decay product Pu-239 ignored due to long half-life)
Cm-244	Default	N/A	N/A (decay product Pu-240 ignored due to long half-life)

**Not available in ERICA, assess as Rn-220*

+Assumed to be in chemically purified forms

4.3.3.2 Gaseous discharges

Radionuclides to be considered in gaseous discharges are detailed in Table 4-5.

Table 4-5: *Radionuclides to be considered for gaseous discharges*

Radionuclide	Included in ERICA	Default decay chain included in assessment of parent	Decay chains that will need to be included[3]
H-3 (HTO)	Default	N/A	N/A
F-18	Non-default	N/A	N/A
Ar-41	Default	N/A	N/A
Kr-79	Not available - assess as one of the other Kr isotopes		
Kr-85	Default	N/A	N/A
Kr-85m	Default	N/A	N/A
Kr-88	Default	Rb-88 (17.8 m)	N/A
Br-82	Non-default	N/A	N/A
I-125	Default	N/A	N/A
I-131	Default	N/A	N/A
Ba-133	Default	N/A	N/A
Xe-133	Default	N/A	N/A
Xe-133m	Default	N/A	N/A
Xe-135	Default	N/A	Cs-135 (2.31 y)

Radionuclide	Included in ERICA	Default decay chain included in assessment of parent	Decay chains that will need to be included[3]
Cs-137	Default	Ba-137m (2.55 m)	N/A
Lu-177	Non-default	N/A	N/A
Pb-212	Default	Bi-212 (1.01 h), Po-212 (299 ns), Tl-208 (3.05 m)	N/A
Rn-219	Not available - assess as Rn-220		
Rn-220	Default	Po-216 (145 ms), Pb-212 (10.64 hr), Bi-212 (1.01 h), Po-212 (299 ns), Tl-208 (3.05 m)	N/A
Ra-223	Non-default	N/A	Rn-219* (3.96 s), Po-215 (1.78 ms), Pb-211 (36.17 m), Bi-211 (2.14 m), Tl-207 (4.77 m)
Ra-224	Default	Po-216 (145 ms), Pb-212 (10.64 hr), Bi-212 (1.01 h), Po-212 (299 ns), Tl-208 (3.05 m)	N/A
Ra-227	Non-default	N/A	N/A (decay product Ac-227 ignored due to long half-life)
Ac-227	Non-default	N/A	Th-227 (18.68 d), Ra-223 (11.43 d), Rn-219* (3.96 s), Po-215 (1.78 ms), Pb-211 (36.17 m), Bi-211 (2.14 m), Tl-207 (4.77 m)
Th-227	Default	N/A	Ra-223 (11.43 d), Rn-219* (3.96 s), Po-215 (1.78 ms), Pb-211 (36.17 m), Bi-211 (2.14 m), Tl-207 (4.77 m)
Th-228	Default	Ra-224 (3.63 d), Po-216 (145 ms), Pb-212 (10.64 hr), Bi-212 (1.01 h), Po-212 (299 ns), Tl-208 (3.05 m)	N/A

**Not available in ERICA, assess as Rn-220*

5 Summary

The IFE is currently responsible for managing several nuclear facilities located in Norway (Kjeller and Halden sites). The split of IFE into three independent divisions requires a new regulatory permit for liquid and airborne discharges to the environment during normal operations for each of them, which is the objective of the work framed in this project.

The environmental impact assessment of the discharges from Kjeller site will be conducted per each of the IFE's divisions following the same base conceptual model in all cases.

The present report presented the work conducted in the frame of the first task of the project focused on developing the conceptual model of the environmental impact assessment. It includes the work done on identifying the main compartments of the system to be modelled, identifying the main processes and mechanisms radionuclides can be dispersed and transported in the environment, identifying the significant exposures pathways and endpoints. Considered endpoints are human and non-human biota.

The assessment will be performed using three different software that have been shortly presented in this report: Ecolego, AERMOD and ERICA.

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